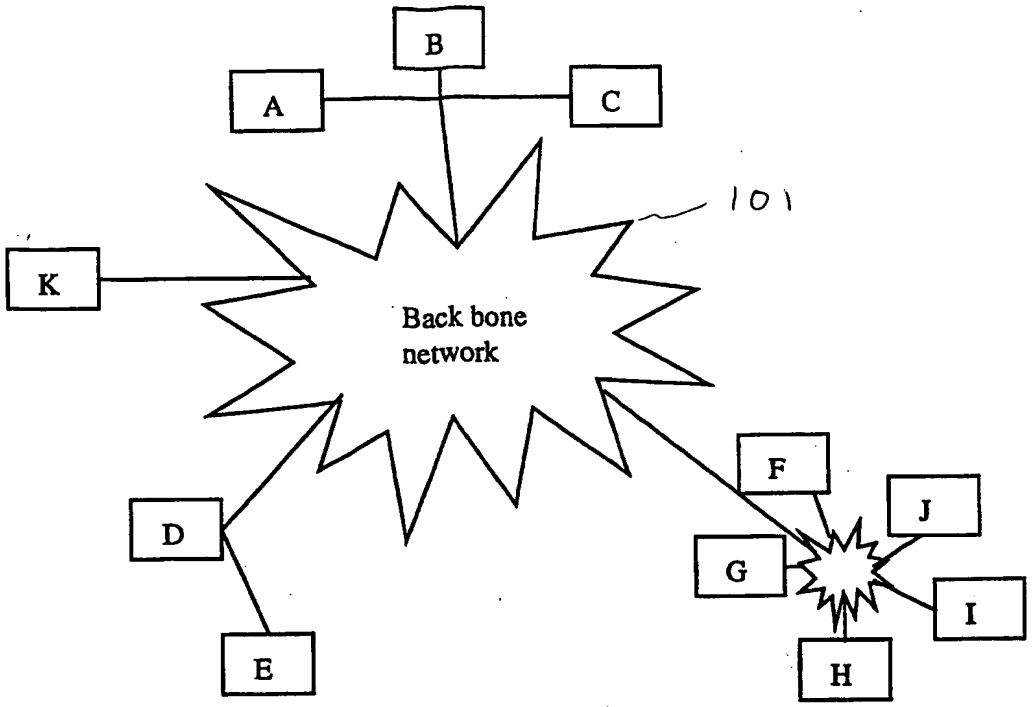


Fig 1

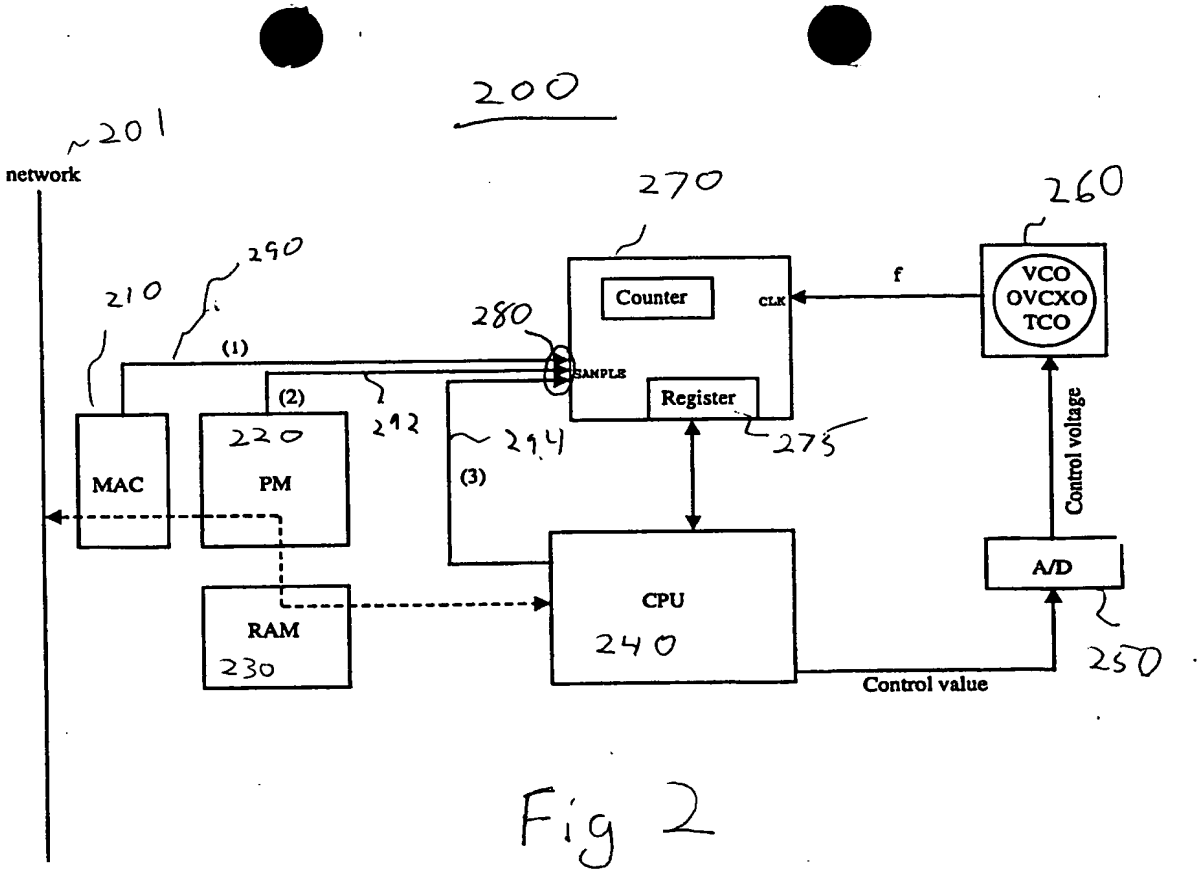

200
201
network
270
260
290
210
280
Counter
CLK
f
VCO
OVCXO
TCO
(1)
SAMPLE
(2)
292
Register
275
294
(3)
MAC
220
PM
Control voltage
A/D
CPU
240
RAM
230
250
Control value

Fig 2

6606E2F" 0676460

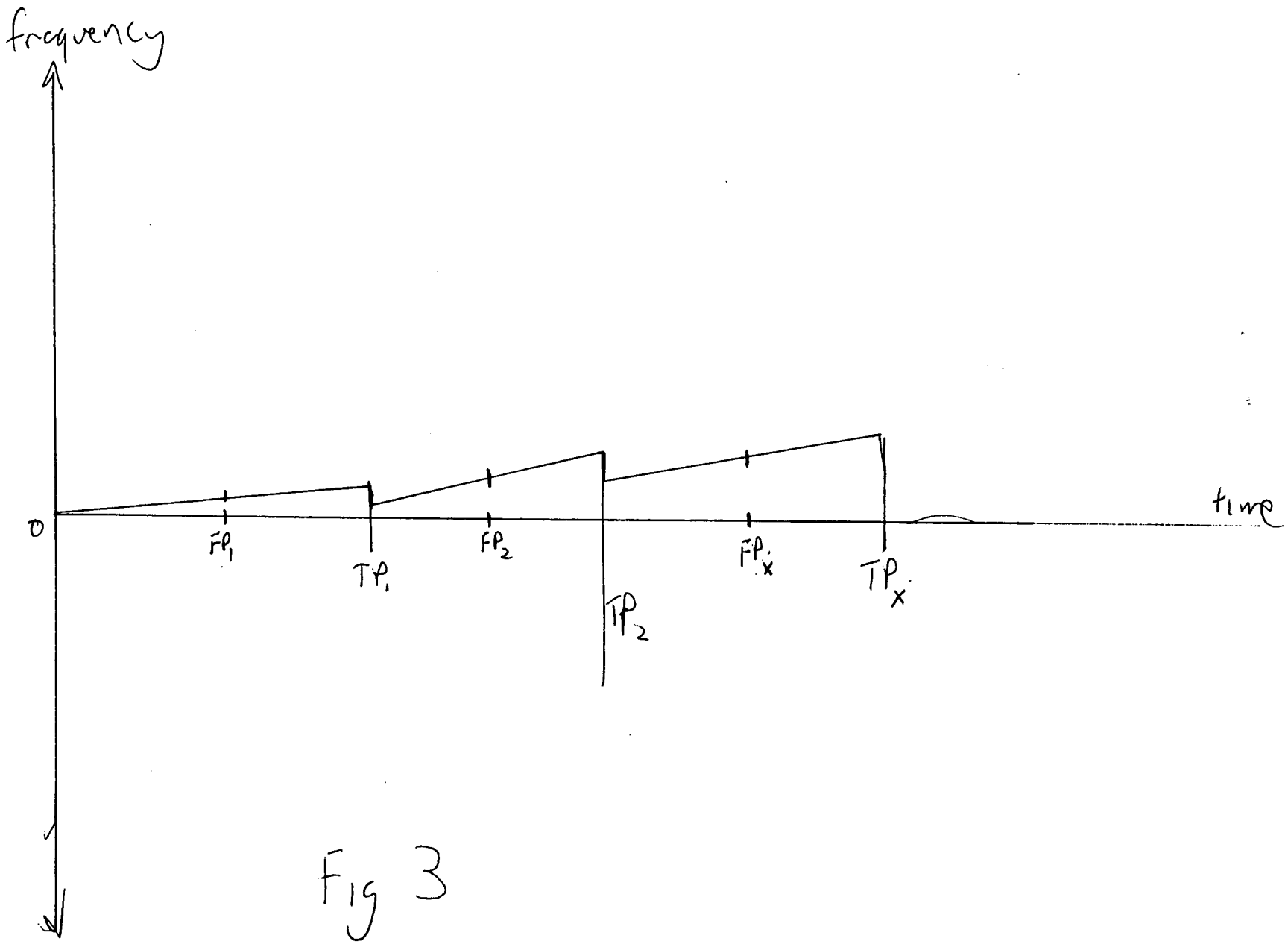


Fig 3

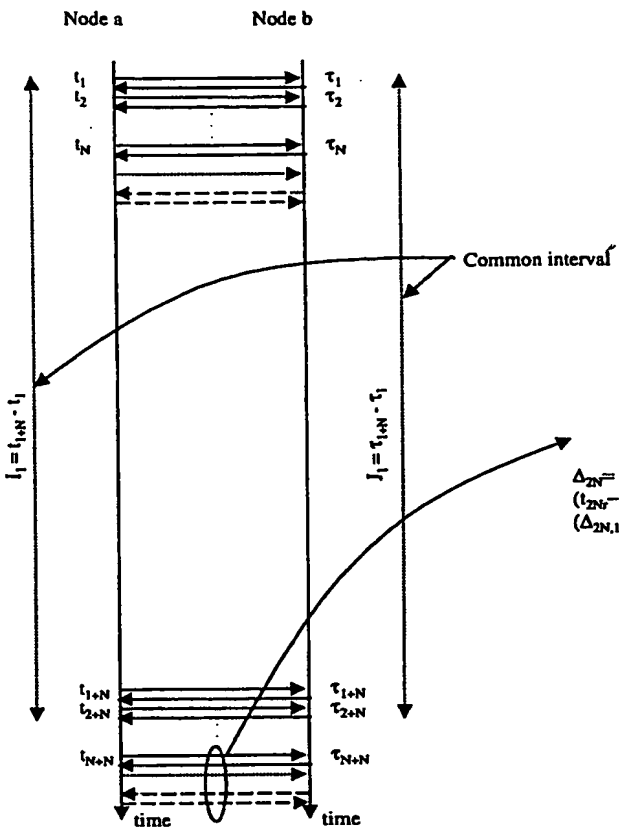

Node a
Node b
t_1
t_2
t_N
τ_1
τ_2
τ_N
Common interval
$I_1 = t_{1+N} - t_1$
$J_1 = \tau_{1+N} - \tau_1$
t_{1+N}
t_{2+N}
t_{N+N}
τ_{1+N}
τ_{2+N}
τ_{N+N}
time
time

Fig 4A

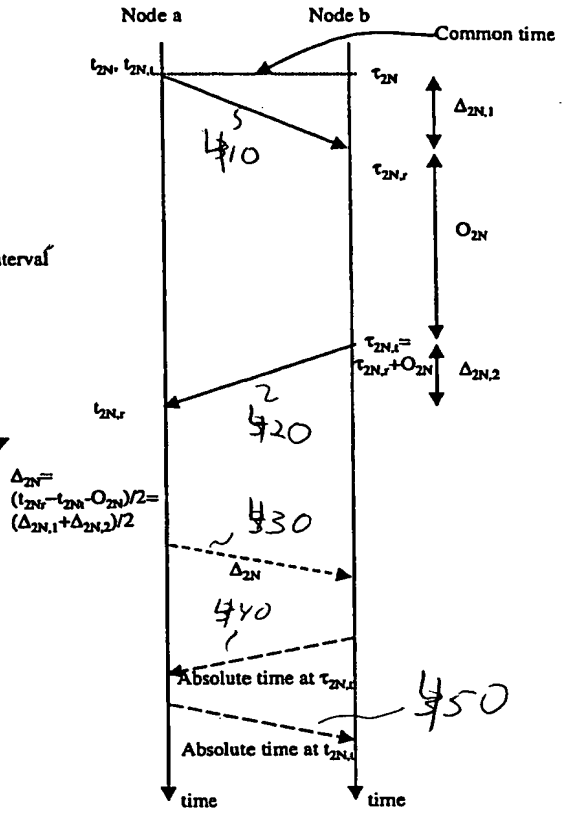

Node a
Node b
Common time
t_{2N}, $t_{2N,1}$
τ_{2N}
$\Delta_{2N,1}$
$\tau_{2N,r}$
O_{2N}
$\tau_{2N,1} = \tau_{2N,r} + O_{2N}$
$\Delta_{2N,2}$
$t_{2N,r}$
$\Delta_{2N} = (t_{2N,r} - t_{2N,1} - O_{2N})/2 = (\Delta_{2N,1} + \Delta_{2N,2})/2$
Δ_{2N}
Absolute time at $\tau_{2N,r}$
Absolute time at $t_{2N,1}$
time
time

Fig 4B

510	520	530	540
Time of Transmission	Last Message Estimated Transmission Delay	Time Interval x_1	Uncertainty Factor (Variance P_{11})

Fig 5

610	620	630	640
Time of Transmission	Time Between The Reception of Time Stamp and This Transmission (O_i)	Time Elapsed Since the Nth Latest Reply Time Stamp Message Was Transmitted	Uncertainty Factor

Fig 6

710	720
Absolute Time When the Last Time Stamp Message Was Transmitted	Uncertainty of the Estimate of Absolute Time

Fig 7

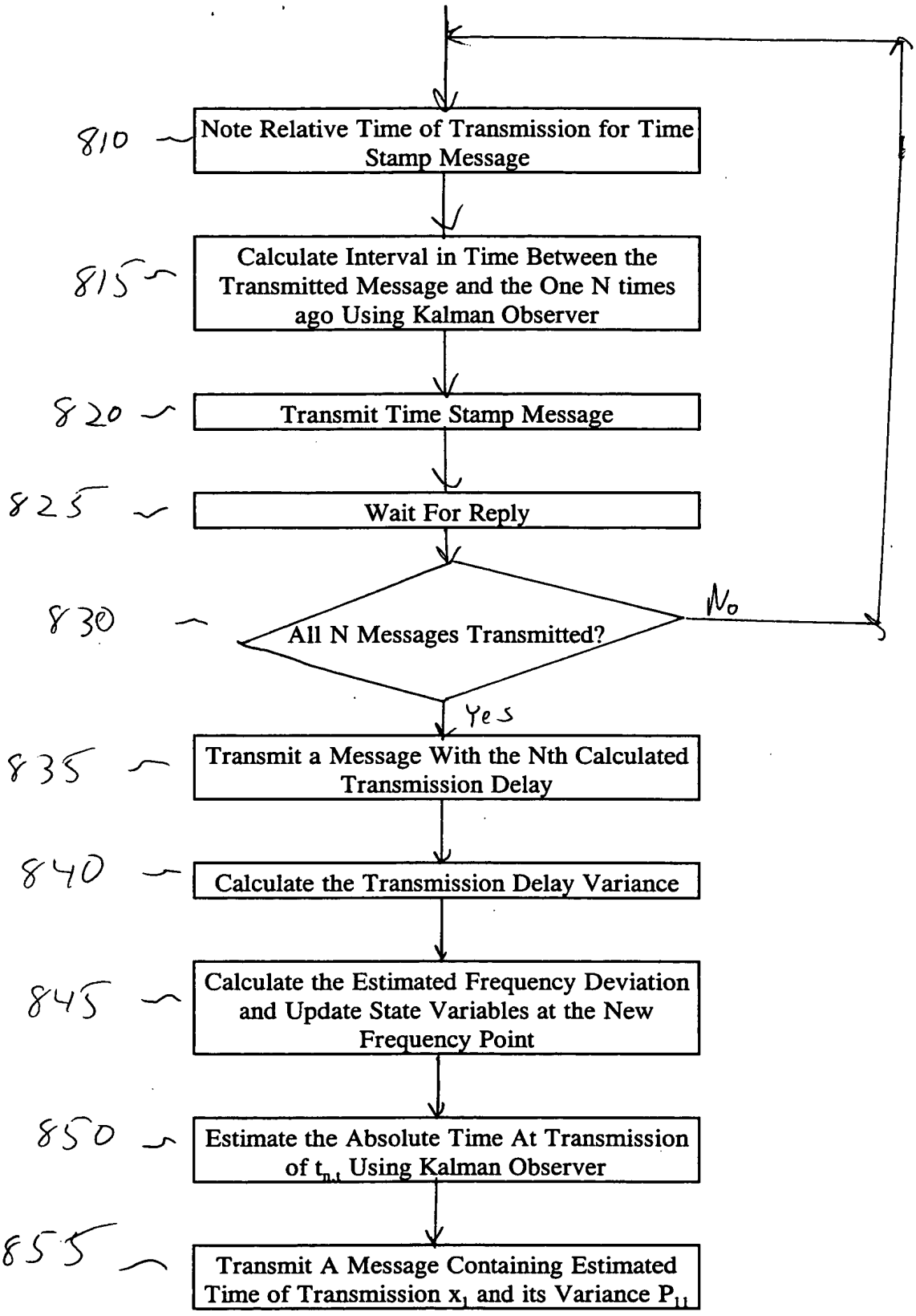

810
Note Relative Time of Transmission for Time Stamp Message
815
Calculate Interval in Time Between the Transmitted Message and the One N times ago Using Kalman Observer
820
Transmit Time Stamp Message
825
Wait For Reply
830
All N Messages Transmitted?
No
Yes
835
Transmit a Message With the Nth Calculated Transmission Delay
840
Calculate the Transmission Delay Variance
845
Calculate the Estimated Frequency Deviation and Update State Variables at the New Frequency Point
850
Estimate the Absolute Time At Transmission of $t_{n,i}$ Using Kalman Observer
855
Transmit A Message Containing Estimated Time of Transmission x_1 and its Variance P_{11}

FIG 8

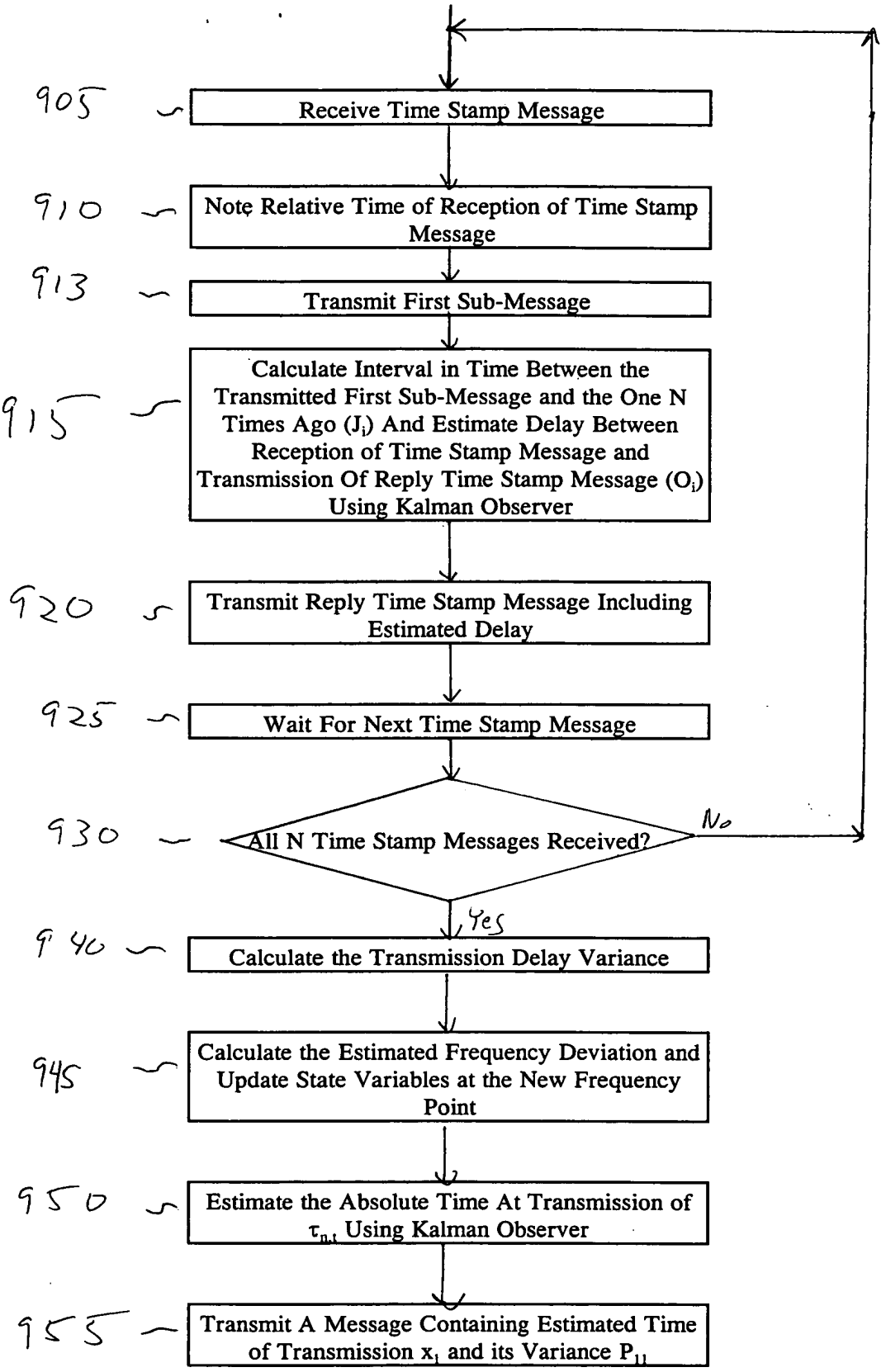

905
Receive Time Stamp Message
910
Note Relative Time of Reception of Time Stamp Message
913
Transmit First Sub-Message
915
Calculate Interval in Time Between the Transmitted First Sub-Message and the One N Times Ago (J_i) And Estimate Delay Between Reception of Time Stamp Message and Transmission Of Reply Time Stamp Message (O_i) Using Kalman Observer
920
Transmit Reply Time Stamp Message Including Estimated Delay
925
Wait For Next Time Stamp Message
930
All N Time Stamp Messages Received?
No
Yes
940
Calculate the Transmission Delay Variance
945
Calculate the Estimated Frequency Deviation and Update State Variables at the New Frequency Point
950
Estimate the Absolute Time At Transmission of $\tau_{n,i}$ Using Kalman Observer
955
Transmit A Message Containing Estimated Time of Transmission x_1 and its Variance P_{11}

FIG 9

6608287 0675460

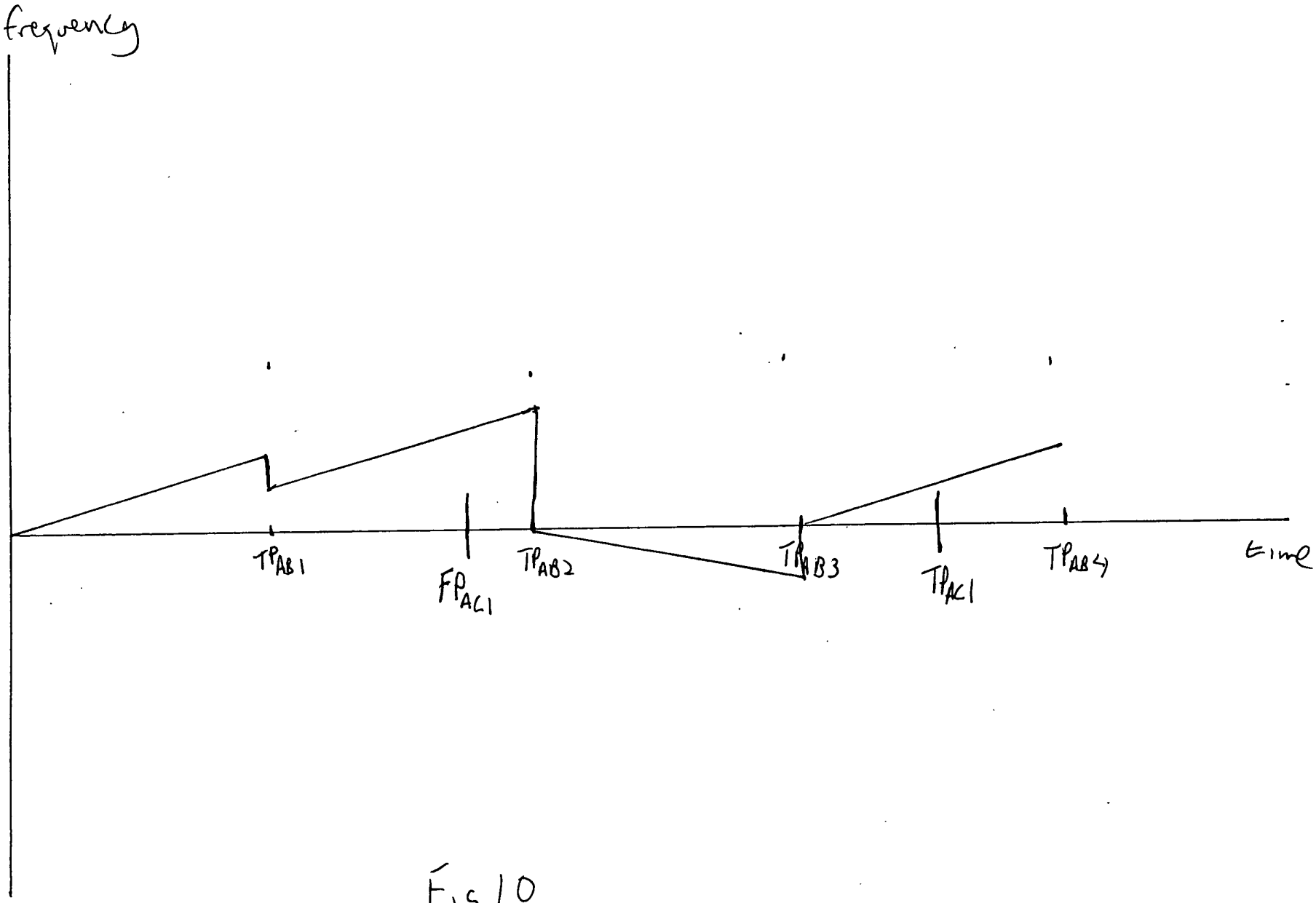


Fig 10

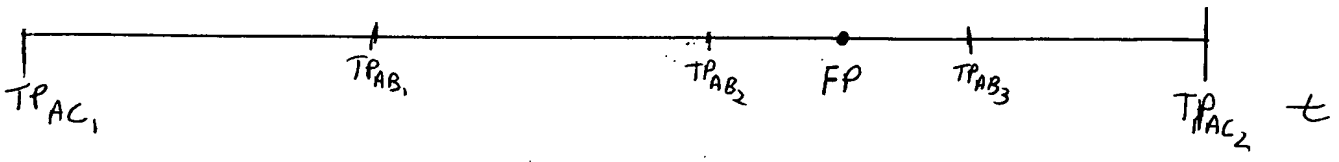


Fig 11a

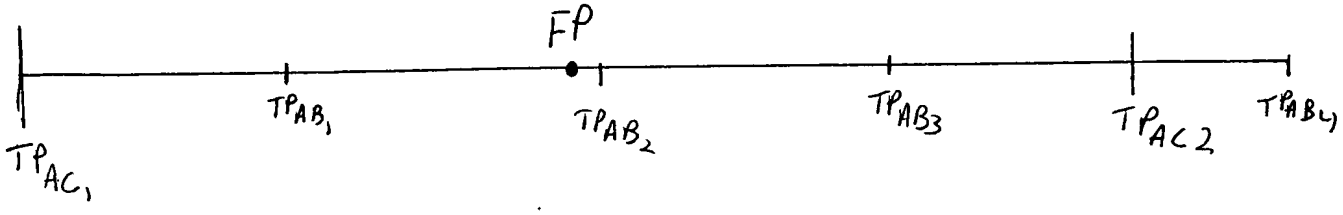
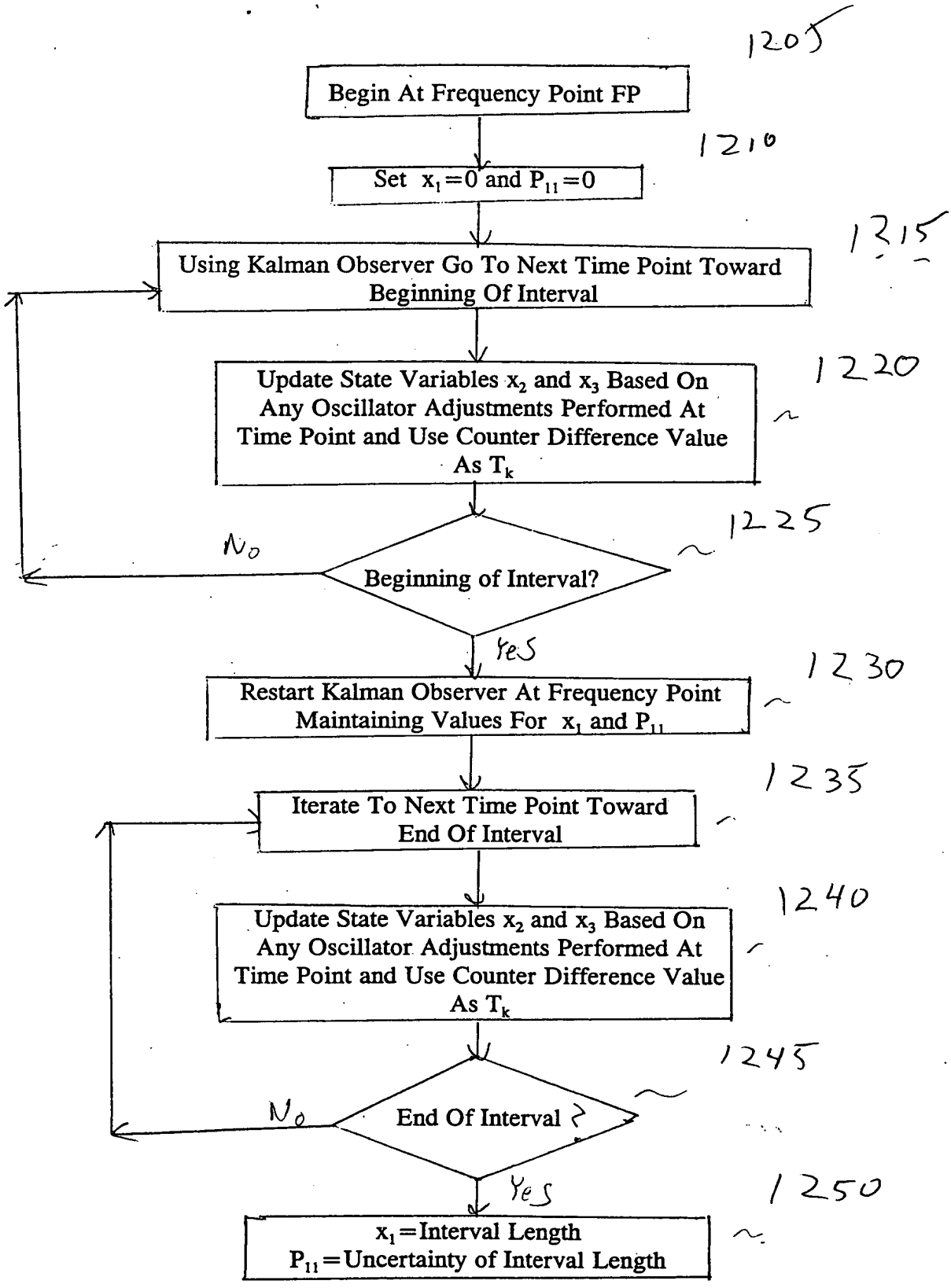


Fig 11b


1205
Begin At Frequency Point FP
1210
Set $x_1=0$ and $P_{11}=0$
1215
Using Kalman Observer Go To Next Time Point Toward Beginning Of Interval
1220
Update State Variables x_2 and x_3 Based On Any Oscillator Adjustments Performed At Time Point and Use Counter Difference Value As T_k
1225
Beginning of Interval?
No
Yes
1230
Restart Kalman Observer At Frequency Point Maintaining Values For x_1 and P_{11}
1235
Iterate To Next Time Point Toward End Of Interval
1240
Update State Variables x_2 and x_3 Based On Any Oscillator Adjustments Performed At Time Point and Use Counter Difference Value As T_k
1245
End Of Interval ?
No
Yes
1250
x_1=Interval Length
P_{11}=Uncertainty of Interval Length

12

FIG

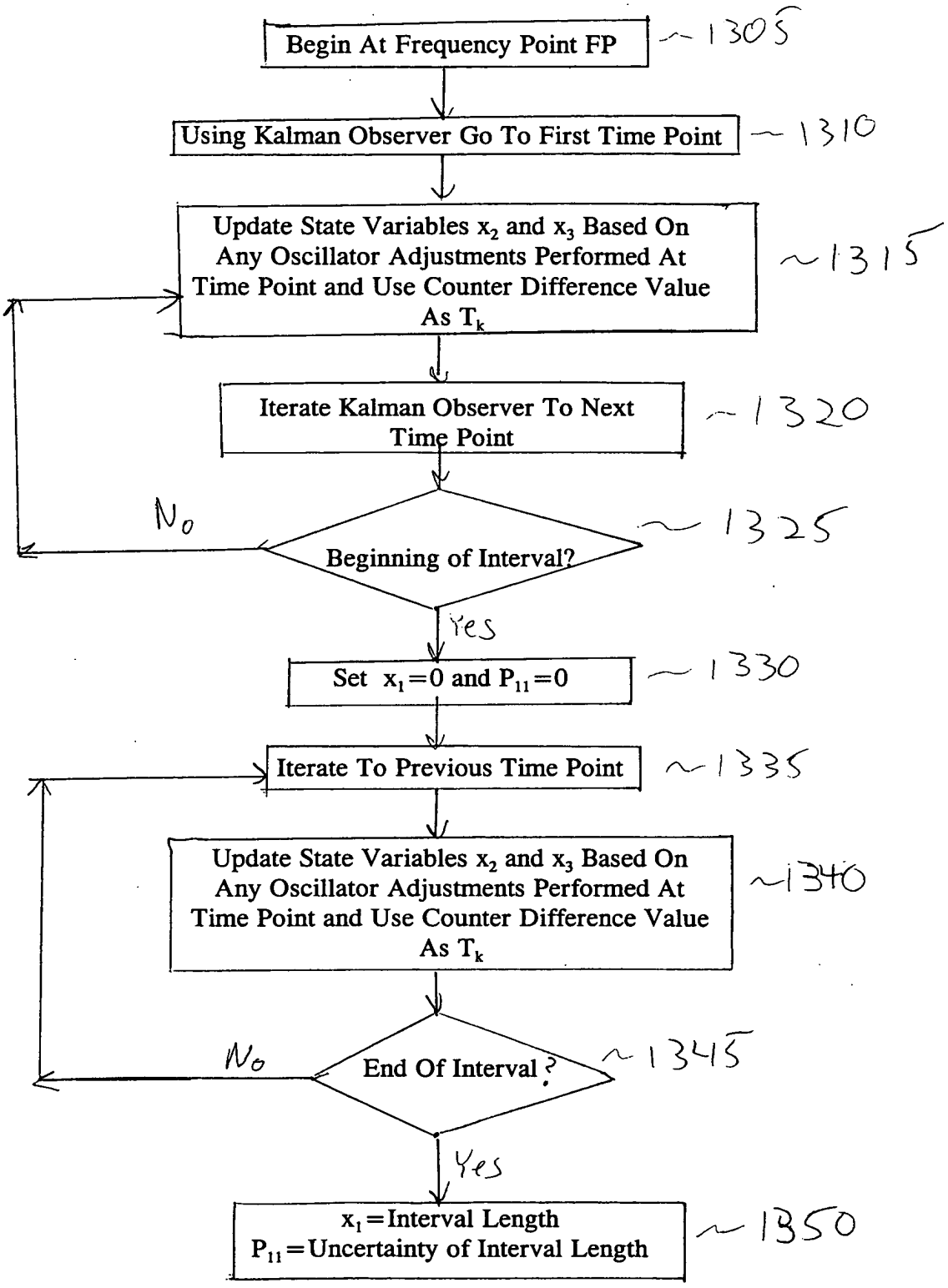

Begin At Frequency Point FP
1305
Using Kalman Observer Go To First Time Point
1310
Update State Variables x_2 and x_3 Based On Any Oscillator Adjustments Performed At Time Point and Use Counter Difference Value As T_k
1315
Iterate Kalman Observer To Next Time Point
1320
No
Beginning of Interval?
1325
Yes
Set $x_1=0$ and $P_{11}=0$
1330
Iterate To Previous Time Point
1335
Update State Variables x_2 and x_3 Based On Any Oscillator Adjustments Performed At Time Point and Use Counter Difference Value As T_k
1340
No
End Of Interval?
1345
Yes
x_1 = Interval Length
P_{11} = Uncertainty of Interval Length
1350

FIG 13

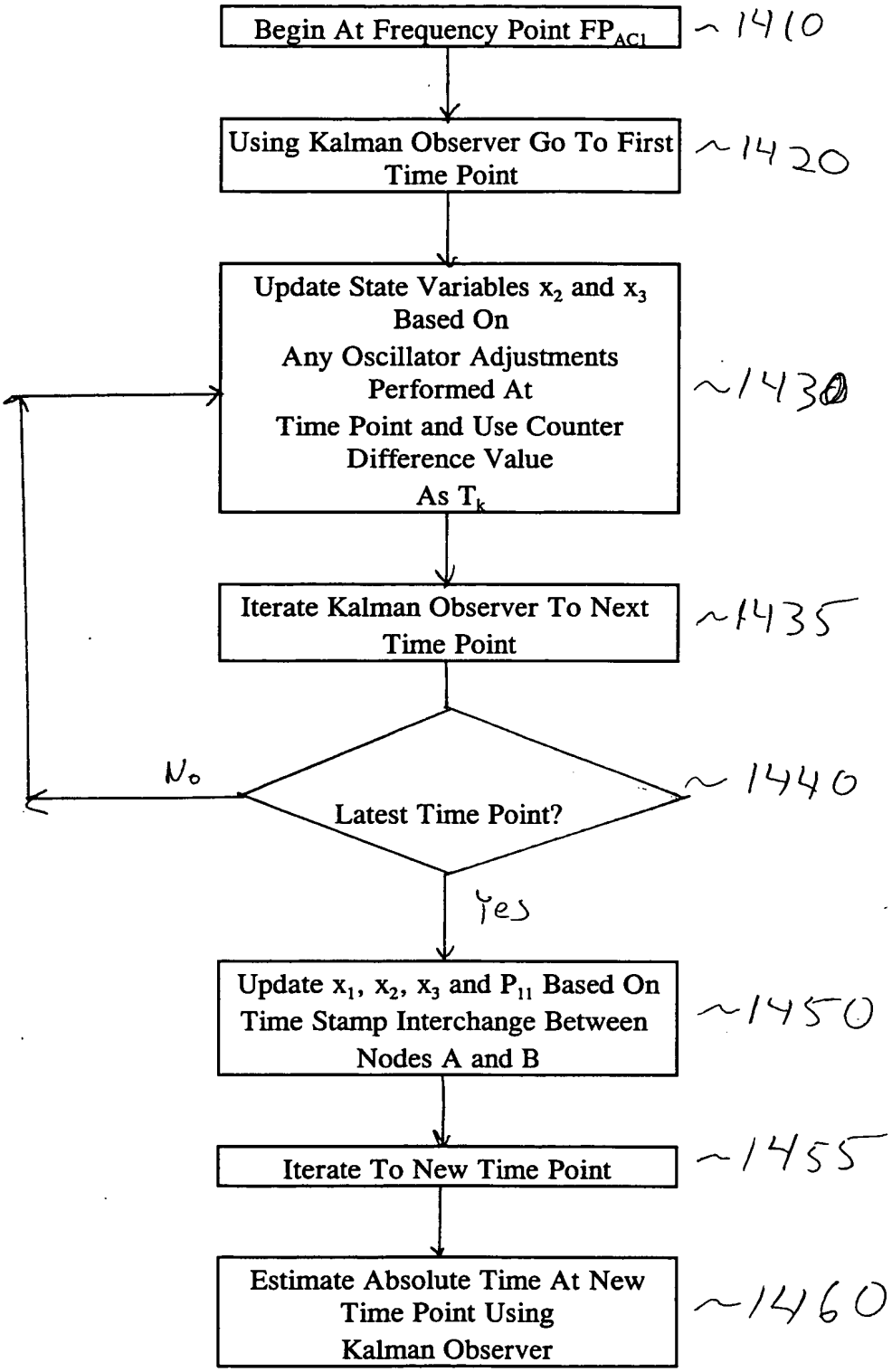

Begin At Frequency Point FP_{ACL}
1410
Using Kalman Observer Go To First Time Point
1420
Update State Variables x_2 and x_3 Based On Any Oscillator Adjustments Performed At Time Point and Use Counter Difference Value As T_k
1430
Iterate Kalman Observer To Next Time Point
1435
Latest Time Point?
No
1440
Yes
Update x_1, x_2, x_3 and P_{11} Based On Time Stamp Interchange Between Nodes A and B
1450
Iterate To New Time Point
1455
Estimate Absolute Time At New Time Point Using Kalman Observer
1460

FIG 14

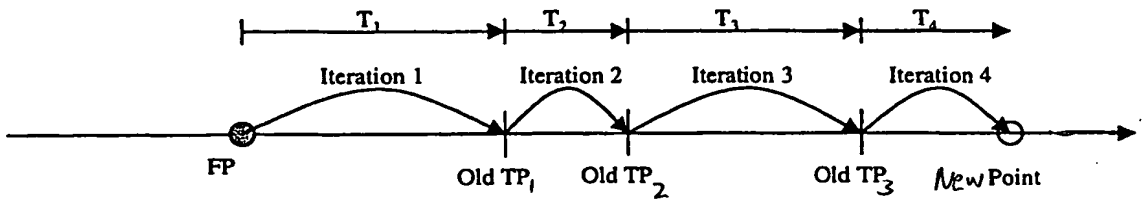

T1
T2
T3
T4
Iteration 1
Iteration 2
Iteration 3
Iteration 4
FP
Old TP1
Old TP2
Old TP3
New Point

Fig 15

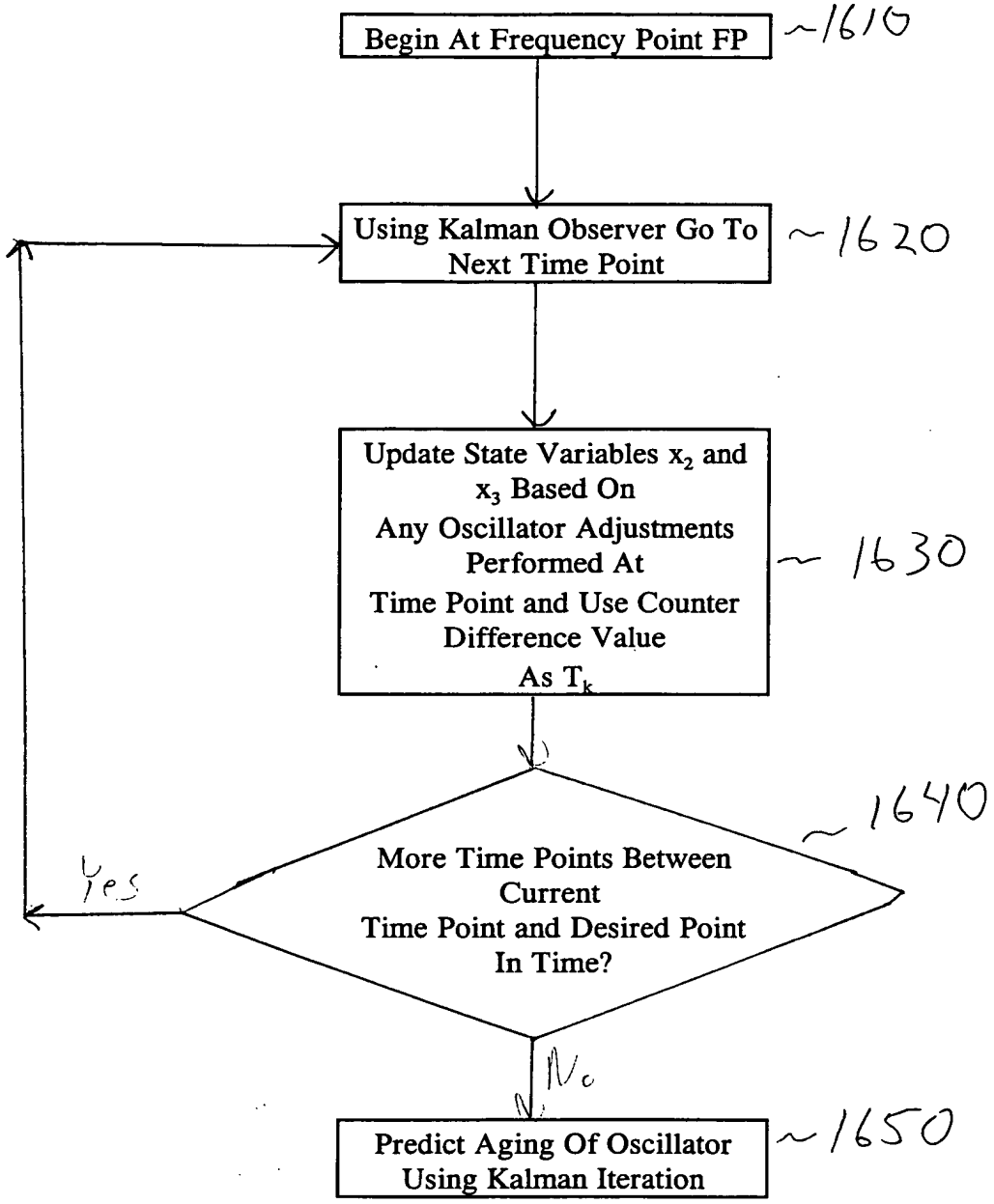

Begin At Frequency Point FP
1610
Using Kalman Observer Go To Next Time Point
1620
Update State Variables x_2 and x_3 Based On Any Oscillator Adjustments Performed At Time Point and Use Counter Difference Value As T_k
1630
More Time Points Between Current Time Point and Desired Point In Time?
1640
Yes
No
Predict Aging Of Oscillator Using Kalman Iteration
1650

FIG 16

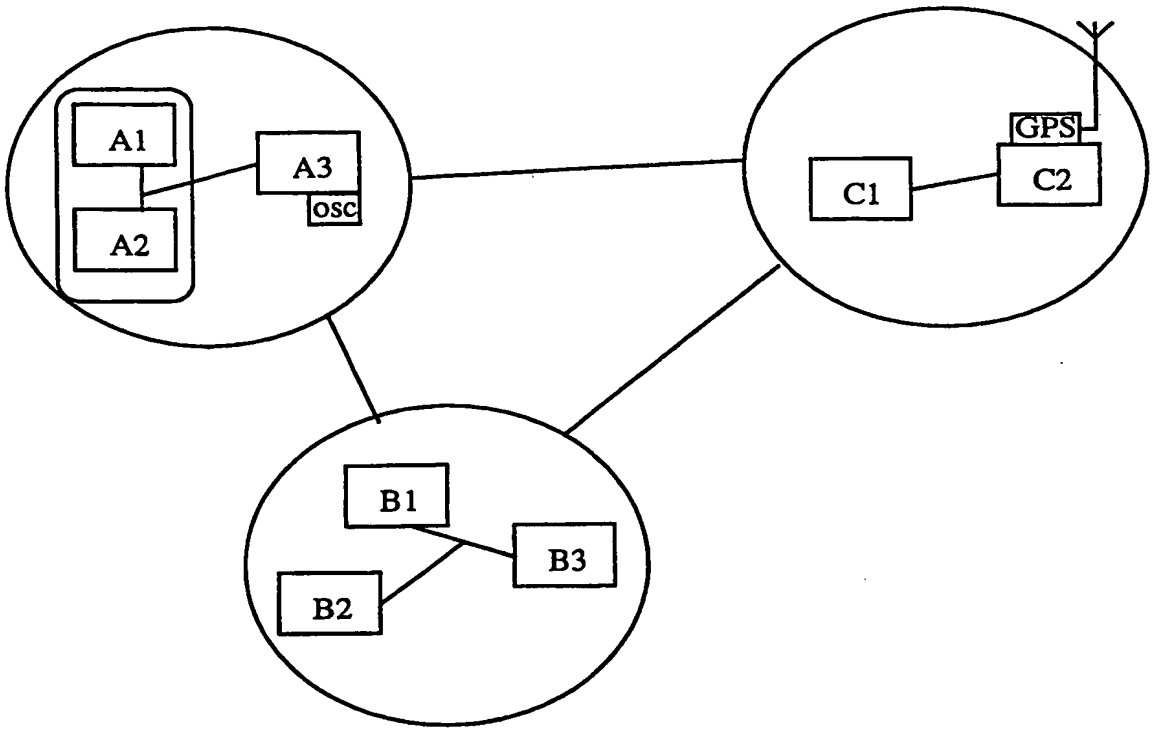


Fig 17

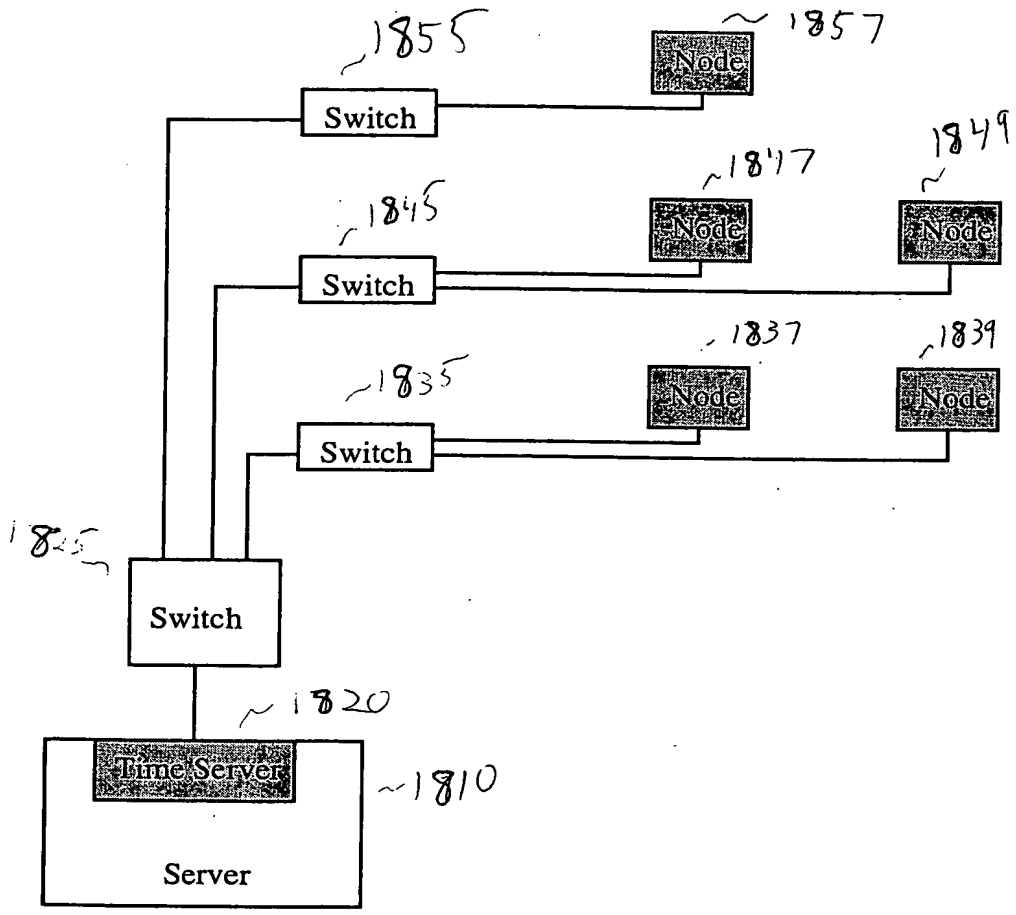

1855
1857
Node
Switch
1847
1849
Node
Node
1845
Switch
1837
1839
Node
Node
1835
Switch
1825
Switch
1820
Time Server
1810
Server

Fig 18